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# AN APPROACH TO DESCRIBE BLOCK-BASED SPATIAL CONFIGURATION

***Abstract:*** *Urban morphology consists of street/block, plot and building. In other words, the entire form of a city could also be divided into two parts: the street pattern and the block layout, both are the objects of urban planning and design. As a network form, the character of the street pattern can be defined by grid pattern, density, connectivity, integration and depth, while the form of the block layout is usually very difficult to be described clearly. In morphologic studies the block layout could be seen as two patterns: the plot pattern and the building pattern, the first one is described by numbers, sizes and various shapes and the latter one depends on the building types and their arrangements. However, these descriptions present the way of composition rather than the form characteristics of the block layout. Since Roger Trancik put forward "figure-ground theory" for urban analysis and design, at this point, urban space has been formally introduced as a "Form" which is concerned as an important "Place" in urban design purposes. Therefore, this paper tries to combine both urban morphologic theories and urban design theories to search for the proper way of the urban spatial characteristics' description and definition.*

*Following Kropf's aspects of plot's connotation: a composition of buildings and external areas, we can find that the most space for the public is composed of the external areas. Choosing the urban blocks set in Nanjing commercial center area of 22 plots, our research focuses on the external areas to analyze the characteristics of the spatial form instead of focusing on buildings. The spatial visibility, geometric property, sight distance and boundary continuity are used to define the spatial characteristics of the urban place combining each plot. Finally, this paper tries to develop a tool to categorize the areas of spaces, so that the characteristics of the block layout could be understood through those types and their compositions.*

***Keywords:*** *Urban Space, Spatial Analysis, Visibility Statistics.*

## Introduction

Urban space is tightly connected to urban morphology. Urban spatial configurations are the basis of urban planning and design. The description and classification of urban space have been broadly and deeply studied and discussed by many researchers.

The research on the spatial form of the city can be traced back to Camillo Sitte, who studied different types of city spaces through specific buildings, and proposed traffic organization methods and street landscapes for modern cities (Sitte 1889). Similarly, other urban planning researchers including Kevin Lynch (1960), Rob Krier (1979) and Alexander Christopher (1987) regard buildings as the basic units of urban morphology in their discussion about the shaping of spatial morphology in the city.

However, taking XinJieKou center district of Nanjing as an example (Fig.1), we can find that it is very difficult to express the spatial characteristics depending on the form of architecture because the forms of buildings are diverse and the organization rules of buildings are complicated. Until now, this problem has not been solved. If the characteristics of the space cannot be expressed clearly, the practice of urban planning in the future is problematic.

Figure 1. The map of XinJieKou center district in Nanjing

From another perspective, people's perception of the city is mostly received in space. The main purpose of urban planning and design is to create better public space. Therefore, describing the form of spaces rather than buildings may be more meaningful. Since Roger Trancik put forward “a figure-ground theory” for urban analysis and design, at this point, urban space has been formally introduced as a “Form” which has been concerned as an important “Place” in urban design purposes.

There are many methods to study the characteristics of space. As a network form, the accessibility, proximity, integration and connectivity of urban space can be analyzed by means of the “space syntax” methodology. A number of authors like Cooper (2000, 2003) employed fractal analysis to characterize the complexity of urban and natural skylines and urban street networks. In urban design Cooper (2000) and Robertson (1992; 1995) looked at fractal dimension in regard to urban design qualities and urban character. Wowo Ding (2011) proposed a new kind of a pattern: a street spatial related line to indicate street spatial characters based on the view shed analysis in GIS. However, there is no conclusion on this issue.

Under the circumstances, many researchers try to use isovist methods, like the spatial visibility, geometric property, sight distance, boundary continuity and a sky view factor to evaluate spaces because people’s perception of moving within such fields could be connected to these geometric properties (Batty, 2001). Isovists and isovist fields shed light on the meaning of prevalent architectural notions about space. In the initial analysis of isovists, Benedikt (1979) identified six geometric measures: the area; the perimeter; the occlusivity; the variance and the skewness of the radials; and circularity. Batty (2001) suggested a feasible computational scheme to measure isovist fields, and illustrate how to visualize their spatial and statistical properties by using maps and frequency distributions.

However, the form of space is difficult to be described in the actual environment because in many cases, pattern of streets and blocks becomes an interlocking form (Kropf, 2013). The urban space is void and undefined. So none of these methods can be used directly. To make further research on the description and classification of the spatial configuration, this article hopes to define and partition the space first, then use a comprehensive method to describe the subspaces and last restore them to the space. There are different ways to partition the space (Fig.2). Different partition ways have different results. Therefore, it is necessary to discuss the quantitative method to describe the subspaces and the partition method.

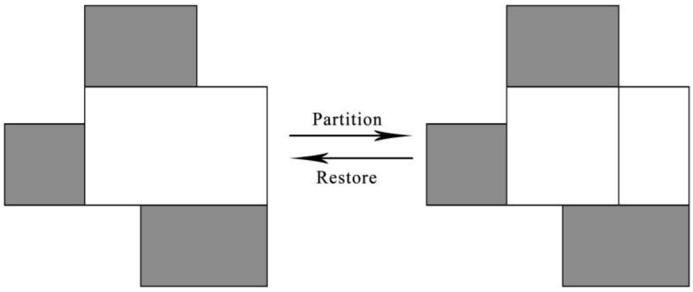


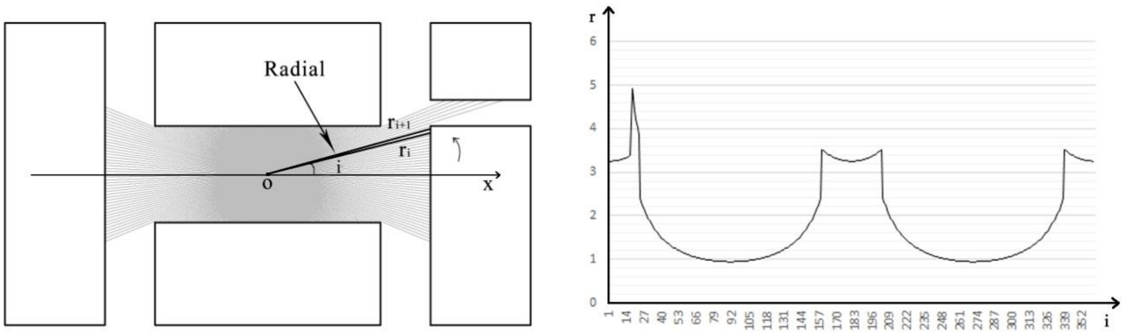

Figure 2. Different ways to partition the space

**Background**

1. Definitions and approaches: isovists and the coordinate system

An isovist is the set of all points visible from a given vantage point in space and with respect to an environment (Benedikt,1979). The set of these spaces forms a visual field whose extent defines different isovist fields based on different geometric properties (Batty, 2001) such as an area and a perimeter. Batty introduces some geometric measures based on a distance, area, perimeter, compactness, and convexity.

The paper starts the research from setting viewpoints in space, which is in the centroid of the space, and tries to find the relationship between isovist fields and the characteristics of the spatial configuration of the block. To express the geometrical form of the isovist, there are two strategies to set the coordinate system. One is to use the traditional way of architectural description, that is, to express the real length of the facade. The other is to express the location of the points which describe the boundary through its angle to the x axis, and the unit of the coordinate system is the measure of an angle. The latter is closer to the human perception and accords with the observation. Therefore, we choose the angle coordinate system to help analyze the spatial characteristics (Fig.3).




(a) (b)

Figure 3. (a) Starting from x axis, we scan the buildings by revolving 360 degrees counter-clockwise around point o to get the length of the radial, which is called ri, i∈1,2,3,…,360. So we can get 360 radials and their lengths. (b) It illustrates the corresponding angle coordinate system. The i axis represents the scanning angle including 360 degrees and the r axis represents the length of the radials.

2. Defining space: convex partitions

When we walk through buildings in the block, we can see changes of the perspective. We usually have to move to another place to see buildings that are obstructed in the previous place. It is impossible to describe the whole space of a block in one place. Peponis et al (1997) mention that "It is always necessary to devise ways for sampling the set of points from which we will draw the isovist …" (page 770). Therefore, finding methods for partitioning space into relevant units is necessary.

Space syntax (Hillier and Hanson, 1984) provides a method for partitioning a spatial system into relatively independent but connected subspaces by defining a convex map as: “the least set of widest spaces that covers the system”, which means that “Simply find the largest convex space and draw it in, then the next largest, and so on until all the space is accounted for”.

However, it is difficult to define the widest space and the largest convex space. Peponis et al (1997) demonstrate that there are many different ways to partition the space under the former definition as illustrated in Figure 4(a). And they suggest that it is possible to generate more convex spaces, which they call an s-partition in Figure 4(b). The advantage of this method is that these subspaces are unique and informationally stable in order to carry out the standard relational analysis. Therefore, we adopt this method to partition the block space.

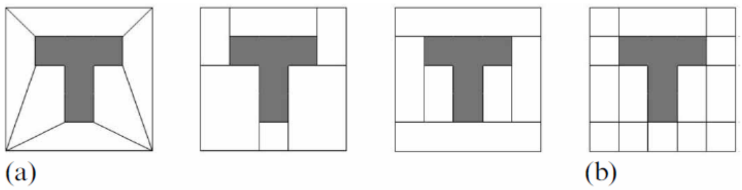
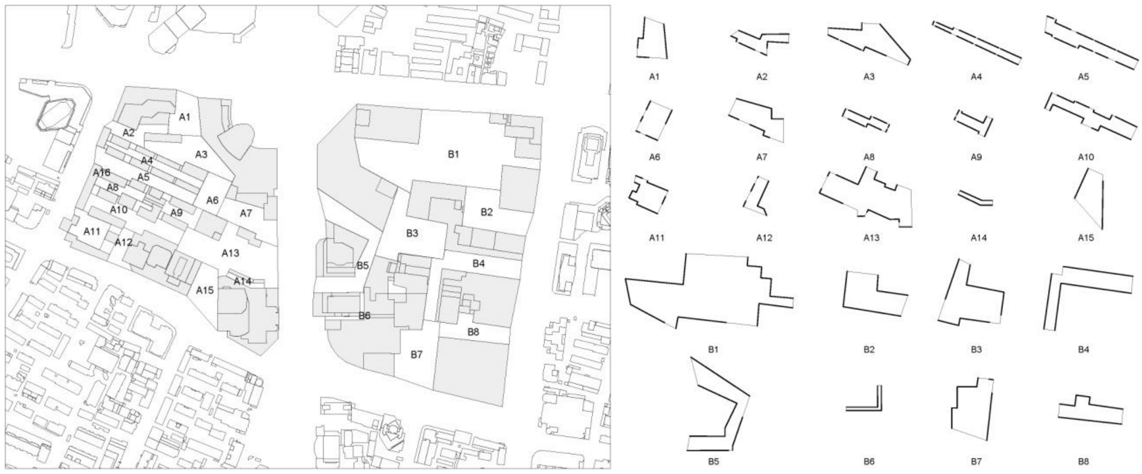



Figure 4. Convex sets and partitions (Batty, 2004)

3. Spatial characteristics

This paper chooses two adjacent blocks set in Nanjing commercial center are that have different characteristics. Block A is a mixed block with residential buildings in the center of the block and commercial buildings around the block, while block B is a pure commercial block with public buildings. There are 16 main spaces in block A and 8 spaces in block B, which are numbered in Figure 5(a). Figure 5(b) illustrates the spaces in two blocks. Building borders of the space are indicated by thick lines and the others are indicated by thin lines.



(a) (b)

Figure 5. (a) Two blocks in Nanjing commercial center area. (b) The spaces in two blocks.

There is a variety of spaces with different characteristics in the blocks. We can conclude that there are four characteristics of the form of the space, which are an area, an aspect ratio, an openness and a circularity. For example, in Figure 6, the area of space B1 is big. The aspect ratio of A14 is big. The openness of space A6 is big because there are many openings around the space. The circularity of A2 is big. The calculation of these characteristics is expressed in the following paragraph.

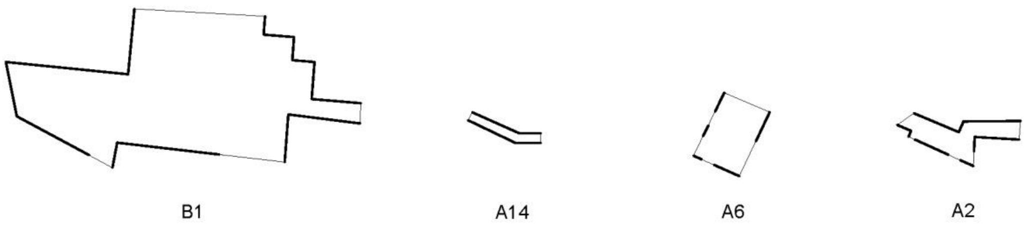



Figure 6. Examples of spatial characteristics in the block.

**Describing the spatial configuration**

Benedikt (1979) identified six geometric measures from which isovist fields could be established: the area of the isovist; the real-surface perimeter of the isovist; the occlusivity of the isovist (or the length of the occluding radial boundary of the isovist); variance of the radials, the skewness of the radials and the circularity of the isovist.

Similarly, this paper develops four measures to describe four features of space: area; standard deviation; openness and circularity. They derive from people's direct perception of space and can be calculated easily by computer programming for further research. These measures are tightly connected to each other. For example, the area has a direct influence on the circularity. So we need to combine all the factors together to evaluate and classify the space. Firstly, we need to define these measures one by one to help understand the meaning of them for further analysis.

1. Area

The area measures how much space can be seen from the viewpoint. It is the basic characteristic of the space (Figure 7). The way of calculation is shown as follows.

$$\text{Area} = \sum \frac{r_i r_{i+1} \sin 1^\circ}{2}, \quad i \in 1, 2, ..., 360$$

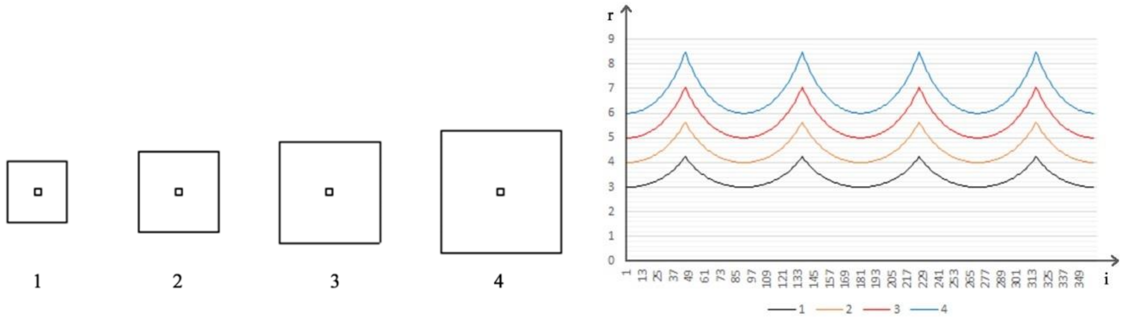



Figure 7. Different areas

2. Standard deviation

The standard deviation measures the dispersion of the perimeter relative to the viewpoint. From Figure 8, we can see that as the aspect ratio of the rectangle becomes larger and larger, the curve in the right graph is becoming more and more discrete. Therefore, the standard deviation can measure the aspect ratio of space, which is an important feature of space. The way of calculation is shown below.$\sigma$represents the standard deviation, and$\mu$represents the average length of radials.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{360}(r_i - \mu)^2}{360}}, \quad i \in 1, 2, ..., 360$$

The urban space is complex and there are many openings in the space. The space of the openings has little effect on the general shape of the space, so the data of the openings need to be excluded. The areas have an effect on the standard deviation. That is, when the aspect ratio is the same, the bigger the area is, the bigger Zhou Changyue is

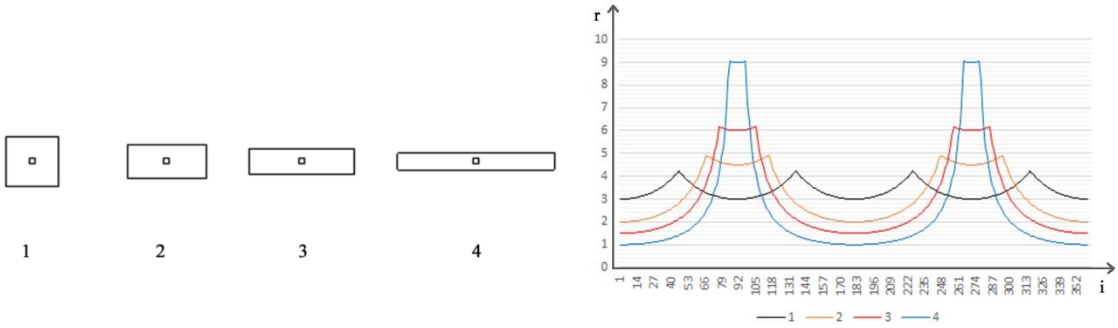
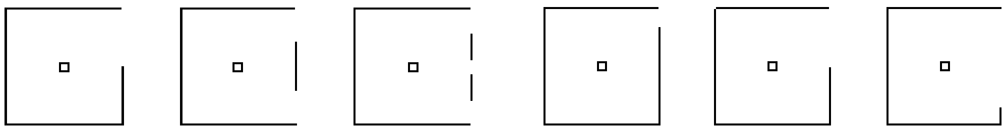



Figure 8. The area is the same, the shape is different

3. Openness

When we walk through the city, we can hardly find completely occluding space. There are many openings in the city, so that we can get more sunshine, ventilation and a field of vision. This characteristic of space is described as the openness, which is related to the amount and angle of the openings (figure 9).



(b)

Figure 9. Different openness. (a) The angle of the opening is same and the amount of the opening is different; (b) The amount of the opening is same and the angle of the opening is different.

Scan the surroundings around the viewpoint and mark a point in the boundary every 1°. Then we will get 360 points and the length of the radials ($r_i$). As it is illustrated in Figure 10, the opening in space is related to the change of the length of the radials, which is called $\Delta r$.

$$\Delta r = |r_{i+1} - r_i|, i \in 1, 2, \ldots, 360$$

When $\Delta r$ suddenly becomes very large, there tend to be an opening in the space.

According to the experiment on the space of blocks in Nanjing, we define that when $\Delta r$ is 10 m, the point is a breaking point, which is marked as a red point in Figure 10. The steps to find the openings are as follows.

First, list all the breaking points around the viewpoint; the number of them is called N. Then calculate the average length of radials between every two continuous breaking points, which is called An, n+1, n∈1, 2, …, N. The part between every two continuous breaking points is an interval and can be called|n, n+1|. From Figure 10 and Figure 11, we can find that some intervals are openings and they have a direct relationship with the change of the average length of every interval radials. To simplify the description, we use the expression of the computer language, which is as follows.

If $A_{n, n+1} > A_{n-1, n}$

If|n-1, n|is an opening

Then|n, n+1|is the same opening

Else

|n, n+1|is the building

Through the analysis and calculation above, we can get the number of openings (No) and the sum of angles of the openings (Ao). When the Ao is same, the bigger the No is, the bigger the openness is. Similarly, when the No is same, the bigger the Ao is, the bigger the openness is. Therefore, we define the openness as follows.

$$\text{Openness} = \frac{\text{No} \times \text{Ao}}{360°}$$

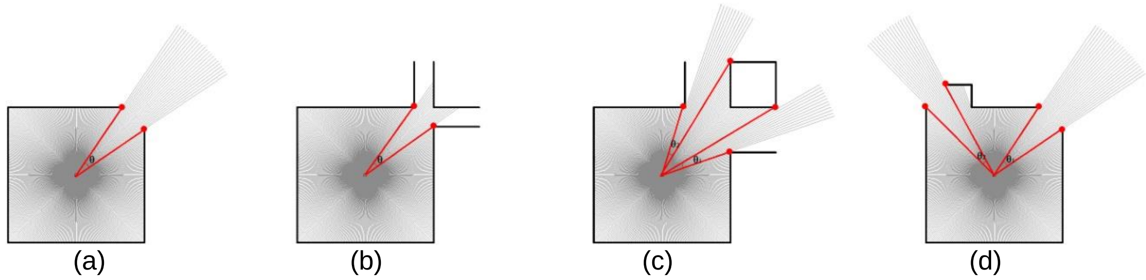



Figure 10. Different openings marked in red

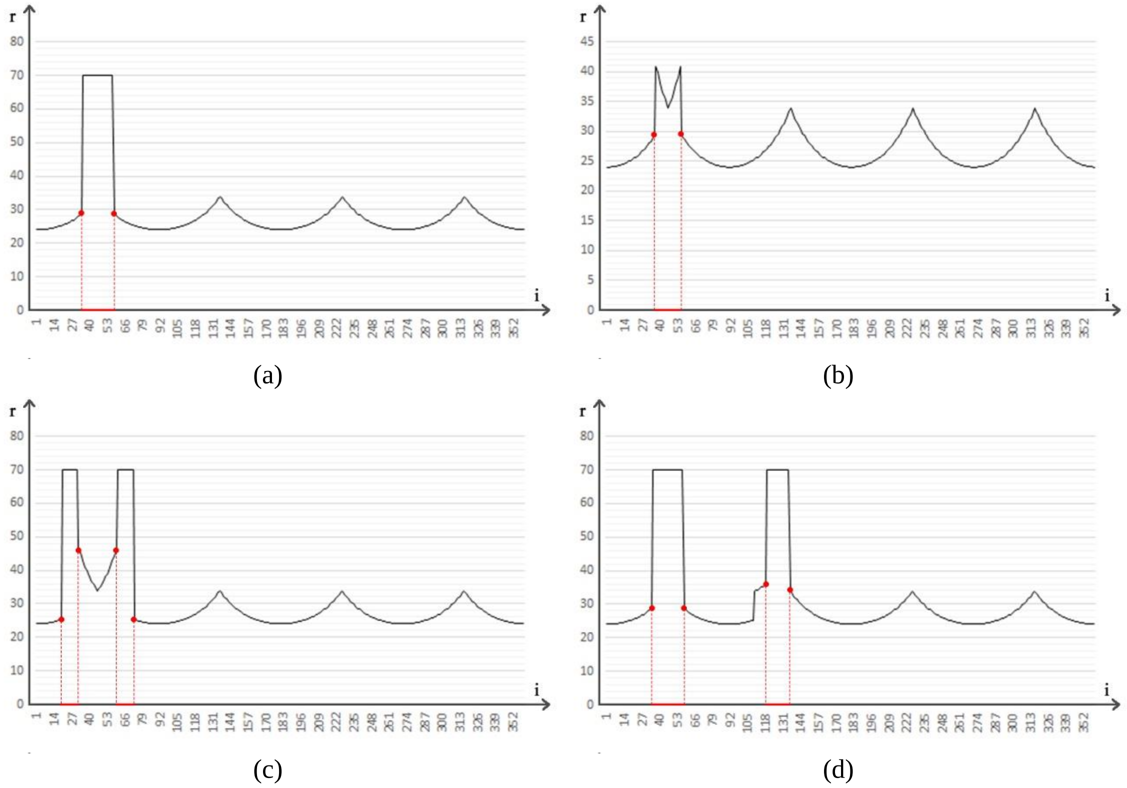



Figure 11. The corresponding curves in the angle coordinate system
and the intervals of openings marked in red

4. Circularity

Davis and Benedikt (1979) define a measure of compactness called circularity as the ratio of the square of the perimeter to the area. Among the geometry with the same area, the circle has the shortest perimeter, followed by the square. With the same area, as the shape becomes more and more irregular, the perimeter becomes bigger and bigger (Figure 12). There are few regular shapes in the city. Therefore, the ratio of the perimeter to the area can describe the convexity (or circularity) of the space. The bigger the circularity is, the bigger the convexity is. The formula is as follows:

$$\text{Circularity} = \frac{\text{perimeter}}{\text{area}} = \frac{\sum \frac{r_i r_{i+1} \sin 1^\circ}{2}}{\sum \sqrt{r_i^2 + r_{i+1}^2 - 2 r_i r_{i+1} \cos 1^\circ}}$$

The area influences the circularity. The larger the area is, the smaller the circularity is. So, it is better to compare the convexity in the same area. Also, considering the openings in urban space, whose distance has little effect on space, only the radials of the building boundary are calculated.

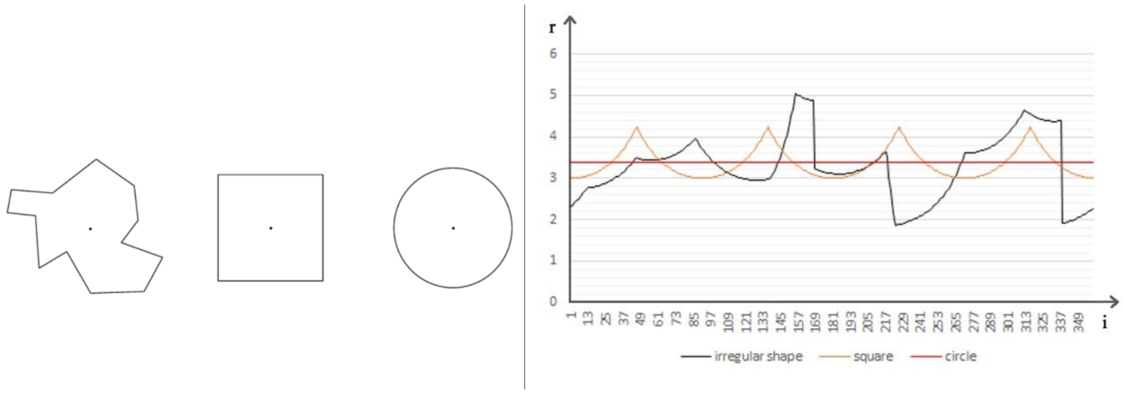



Figure 12. The area is same but the shape is different.
The circularity of each shape is 0.82, 0.67 and 0.59

## Experimentation in Xinjiekou

1. Data collection

First, according to the partitioning method mentioned above, the spaces in two blocks are divided into a lot of subspaces. Then we set viewpoints in the centroid of every subspace and we can find that there are 323 points in block A and 83 points in block B (Fig.13). Every point has corresponding data that reflects the feature of the space around the viewpoint and it is the basis of the following analysis. There is so much data that we must use computer software to help calculate and analyze.

Our data processing pipeline is as follows: we use grasshopper to collect data and export it to .txt files, and then we use data analysis tools in Python programming language, such as pandas and numpy, to do the calculation. After inputting these data into the computer and computer calculation, we get four measures of every subspace. But there are so many subspaces that we cannot make a classification readily. To simplify the process and get more correct result, it is necessary to merge some subspace into one space according to the actual condition. In the city, adjacent spaces seem to have similar characteristics. So we integrate adjacent subspaces manually that are numbered in Figure 5(a).

Figure 13. Subspaces and viewpoints in the blocks

2. Data analysis

There are four measures to describe the spatial configuration: area; standard deviation; openness and circularity. We calculate the measures of spatial characteristics of two blocks in Nanjing commercial center area and use these data for comparison and analysis (Table 1 and Table 2).

Table 1

Basic statistics of spaces in two blocks

| | Area | Standard Deviation | Openness | Circularity |
|---|---|---|---|---|
| A1 | 12646 | 20.21 | 0.63 | 0.06 |
| A2 | 5090 | 6.00 | 0.59 | 0.20 |
| A3 | 7369 | 8.41 | 0.66 | 0.12 |
| A4 | 3953 | 15.73 | 0.36 | 0.15 |
| A5 | 7380 | 17.79 | 0.58 | 0.17 |
| A6 | 9859 | 20.22 | 0.46 | 0.06 |
| A7 | 21020 | 18.04 | 0.74 | 0.04 |
| A8 | 2357 | 5.80 | 0.29 | 0.23 |
| A9 | 2547 | 6.51 | 0.45 | 0.21 |
| A10 | 8133 | 8.85 | 0.53 | 0.15 |
| A11 | 4654 | 7.06 | 0.66 | 0.12 |
| A12 | 8173 | 14.77 | 0.69 | 0.09 |
| A13 | 20755 | 35.20 | 0.94 | 0.05 |
| A14 | 3577 | 11.71 | 0.14 | 0.12 |
| A15 | 16524 | 27.14 | 0.53 | 0.05 |
| B1 | 24637 | 28.16 | 0.62 | 0.04 |
| B2 | 16170 | 23.52 | 0.36 | 0.05 |
| B3 | 13639 | 10.51 | 0.36 | 0.06 |
| B4 | 10417 | 17.22 | 0.17 | 0.08 |
| B5 | 8353 | 26.33 | 0.18 | 0.08 |
| B6 | 1231 | 12.98 | 0.04 | 0.41 |
| B7 | 14907 | 22.84 | 0.46 | 0.06 |
| B8 | 6636 | 21.49 | 0.31 | 0.10 |

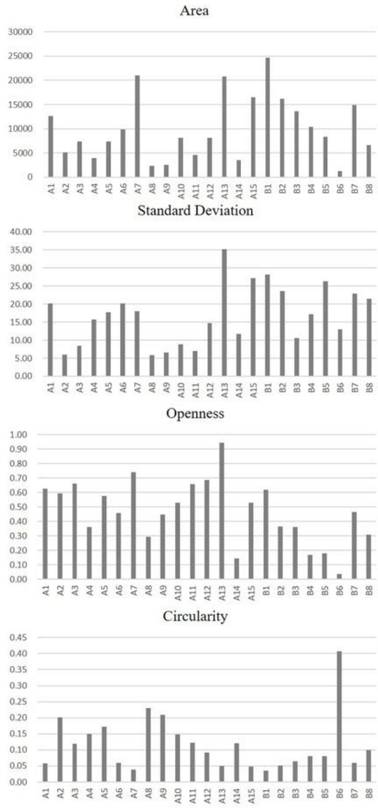



Table 2

Average statistics of spaces in two blocks

| | Area | Standard Deviation | Openness | Circularity |
|---|---|---|---|---|
| A | 8936 | 14.90 | 0.55 | 0.12 |
| B | 11999 | 20.38 | 0.31 | 0.11 |

Based on the average statistics, we could describe the general spatial characteristics.

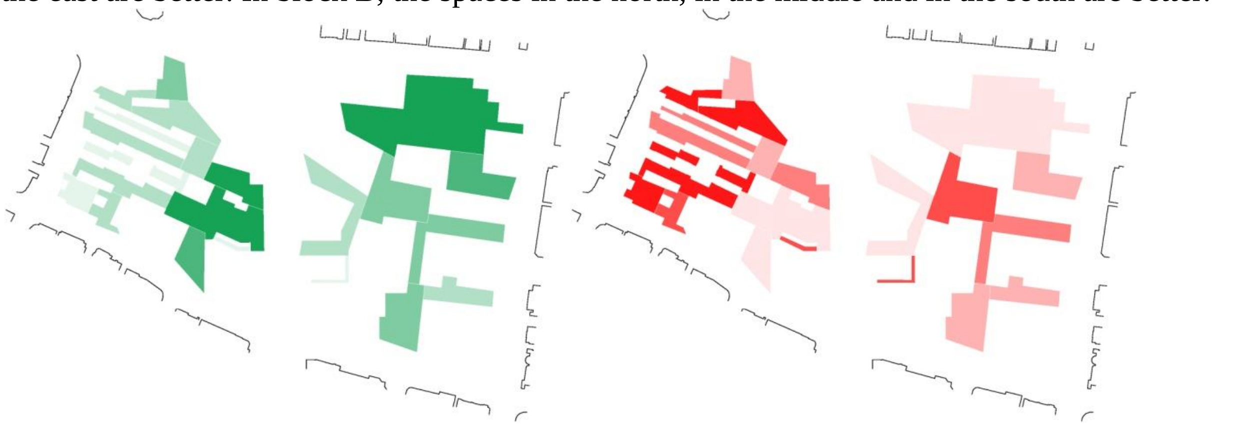
- The average area of block B is bigger than block A. It means that the public space in block B is relatively bigger. Besides, the difference in area in block A is more obvious than the difference in area in block B. It means the area of space is more evenly distributed. Because there are many small spaces in block A which is near the residential buildings and there are some big spaces next to the street.
- The average openness of block A is much bigger than that of block B. Mainly because there are many small residential buildings in block A, which tend to create more openings in the space. While the buildings in block B are relatively bigger and the number of buildings is smaller.
- Some measures are related to the area. When the shape of the space is the same, the openness and circularity increases with the increase of the area. Therefore, when the area is the same, the comparison is meaningful. For example, the area of space A6 and space A4 are similar. The openness of space A6 is 0.46, while that of space B4 is 0.17. It shows that space A6 is much more open than space B4, which indicates that there is more

ventilation in space A6 when other conditions are the same. Besides, the circularity of space A6 is 0.06 and that of space B4 is 0.08. It means that the convexity of two spaces is similar. We can also see that the standard deviation of space A6 is 20.22 and that of space B4 is 17.22. It seems that the aspect ratio of space A6 is a little bit bigger. But there are so many cracks in space A6. As a result, it is almost meaningless to discuss this.

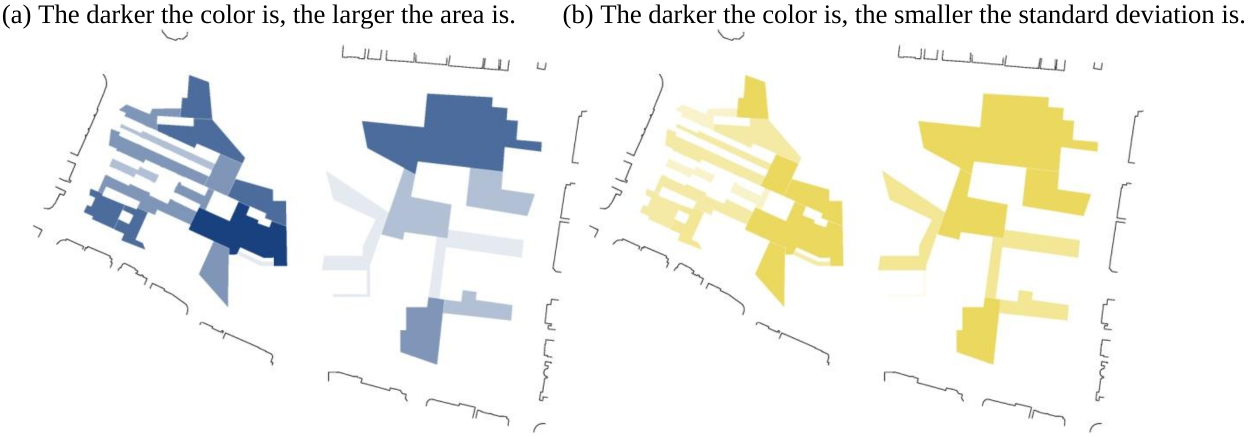
- The area, standard deviation and circularity of the space have little influence on the openness, since the openness is only affected by the angle and number of the openings. For instance, we can make a comparison between space A6 and space B2. The area of space A6 is 9858 square meters, which is much smaller than the area of space B2 (16170 square meters). The standard deviation and circularity of the space are similar. The openness of space A6 is 0.46, while the openness of space B6 is 0.36. Although with smaller space, space A6 even has greater openness because there are many openings around space A6. In comparison, the surrounding buildings of space B2 are closed, which lead to relatively smaller openness.

We can also map the statistics with different colors to help understand the values clearly (Fig.14). In block A, large public spaces are mainly located in the east. The spaces in the middle are closed, and the spaces in the north and east are open. In block B, large public spaces are mainly located in the north. The spaces in the middle are closed, and the spaces in the north and south are open. Besides, the area has a great effect on the standard deviation and circularity. The larger the area is, the larger the standard deviation is and the smaller the circularity is. Therefore, it is much better to compare the standard deviation and circularity of the spaces with the same area.

Good urban public space is usually larger, more open, has smaller aspect ratio and smaller circularity. So we superimpose the colors to help look for better public space(Fig.15). We can find that the spaces in the middle and in the west in block A are well-distributed and the spaces in the east are better. In block B, the spaces in the north, in the middle and in the south are better.



(a) The darker the color is, the larger the area is. (b) The darker the color is, the smaller the standard deviation is.



(c) The darker the color is, the larger the openness is. (d) The darker the color is, the smaller the circularity is.

Figure 14. Mapping four measures of spatial characteristics of the blocks

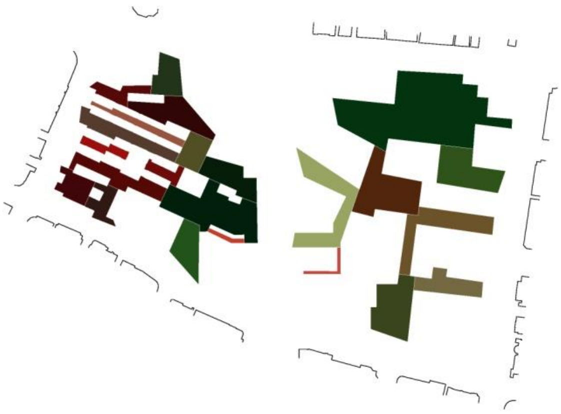


Figure 15. Superimposing all the colors

## Conclusion

Whether for a formal analysis or for design making in urban design and planning, it is very important to study space and find the method to quantify its characteristics it in urban morphological research. The purpose of this paper is to explore the method of quantizing the spatial features. The steps are as follows:

- Choose a block and partition the space inside the block into a series of convex spaces.
- Set viewpoints in the centroid of these subspaces and get statistics of isovists of these points.
- Analyze the data and calculate the area, standard deviation, openness and circularity of these spaces.
- Merge the subspaces into several different spaces.
- Describe the characteristics of the spaces by calculating the average area, openness and circularity and the minimum of the standard deviation.

Based on the comparison of the four measures for different spaces in the block, we can evaluate the space of a complex block.

Our experiments have shown that urban space of a block can be simulated by group data of viewpoints set in the block. It can help us understand urban space better in the following ways.

First, based on the analysis of the curves' pattern in the angle coordinate system, we find this pattern reflects the urban spatial characteristics effectively. The study shows that it is not only meaningful, but also of great potential to do research on this pattern.

Second, we conclude four measures based on the observation inside the block: area; standard deviation; openness and circularity to describe the entire characteristics of the space in the block. The advantages of this method are that it not only describes the spatial characteristics of the space but also shows the physical position of the spatial variation, which is helpful for urban design research.

Third, the data of isovists are collected and processed by the computer software which is helpful to analyze and study complicated space in a city.

As this research is still in its initial stage, there are some problems that need to be solved and there is much work to be done. Two of the measures, standard deviation and circularity, are not scale invariant and they interact with each other sometimes. Besides, as we only choose two blocks in Nanjing commercial center area, more experiments are needed to verify this method.

Acknowledgement

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**Illustrations and tables**